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Research Paper / Araştırma Makalesi

Water Reuse via Membrane Technology: A Case Study for Producing Cooling Water from Soft Drink Wastewater

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ABSTRACT

High volumes of water are used in the soft drink industry, where purification can be achieved via membrane technology, allowing it to be reused in operating cooling towers, steam boilers, and closed-loop systems. In this study, ultrafiltration (UF) and nanofiltration (NF) were applied to produce reclaimed water for cooling towers. In experimental studies conducted under a total recycle mode of operation, two UF membranes with molecular weight cut-offs (MWCO) of 10 kDa and 5 kDa, and one NF membrane were tested. The transmembrane pressure was set to 2 bars for UF and 4 bars for NF. Considering the water quality criteria for cooling towers, removal efficiencies were calculated for total suspended solids (TSS), turbidity, and chemical oxygen demand (COD). TSS and turbidity removal rates were 100% for both UF and NF; however, COD removal rates varied. In UF, feed and permeate COD concentrations were 718 - 796 mg/L and 255 - 286 mg/L, corresponding to a removal efficiency of 64-65%. On the other hand, in NF, the feed and permeate COD concentrations were 207 mg/L and 147 mg/L, indicating a 29% removal. Flux decline was not severe; it ranged from 10% to 20%. It was revealed that further treatment is required to meet the COD criteria of 75 mg/L for cooling towers.

Keywords: Cooling tower, Membrane processes, Nanofiltration, Soft drink wastewater, Ultrafiltration

Membran Teknolojisi ile Su Geri Kazanımı: İçecek Atıksuyundan Soğutma Suyu Üretimi Üzerine Örnek Bir Çalışma

ÖZ

Yüksek miktarda su kullanılan içecek sektörü atık suları membran teknolojisi ile arıtılarak soğutma kuleleri, buhar kazanları ve kapalı devre sistemlerin işletilmesinde tekrar kullanılabilmektedir. Bu çalışmada içecek üretimi atıksuyundan soğutma kuleleri için su elde etmek amacıyla ultrafiltrasyon (UF) ve nanofiltrasyon (NF) uygulanmıştır. Toplam geri çevrim modunda yürütülen deneysel çalışmalarda, moleküler ağırlık ayırma sınırı (MWCO) 10 kDa ve 5 kDa olan iki UF membranı ve ayrıca bir NF membranı test edilmiştir. Trans membran basıncı UF için 2 bar, NF için 4 bar olarak ayarlanmıştır. Soğutma kuleleri için su kalitesi kriterleri dikkate alınarak toplam askıda katı madde (AKM), bulanıklık ve kimyasal oksijen ihtiyacı (KOİ) için giderim verimleri hesaplanmıştır. UF ve NF için AKM ve bulanıklık giderimleri %100 olmuştur, ancak KOİ giderimleri değişkenlik göstermiştir. UF için besleme ve süzüntü suyunda KOİ konsantrasyonu sırasıyla 718-796 mg/L ve 255-286 mg/L olmuş; %64-65 giderim verimi elde edilmiştir. Öte yandan, NF besleme ve süzüntü suyunda ise KOİ konsantrasyonu sırasıyla 207 mg/L ve 147 mg/L olarak ölçülmüş, %29 giderim verimi elde edilebilmiştir. Akı azalması çok yüksek olmamış; %10 ile %20 arasında kalmıştır. Soğutma kuleleri için KOİ sınır değeri 75 mg/L olması nedeniyle, ilave arıtma işlemine ihtiyaç olduğu ortaya konmuştur.

Anahtar Kelimeler: İçecek atıksuyu, Membran prosesleri, Nanofiltrasyon, Soğutma kulesi, Ultrafiltrasyon

INTRODUCTION

The sustainability of freshwater resources is under threat due to the worldwide population growth, economic development, environmental pollution and climate change. Türkiye is among the water-stressed countries. The increased demand for water as a result of urbanization, agricultural production and industrial activities have negative impacts on water resources.

The leading sectors in water use in Türkiye can be classified as agriculture, industry and urban/domestic use. The States Hydraulic Works [1] reports that 77% of freshwater resources are used for agricultural production, and the remaining 23% is shared between industry and domestic use. According to Turkish Statistical Institute [2], a total of 19.2 billion m^3 of water was withdrawn in 2022; of which 56.8% was from the sea; 43.2% was from freshwater resources, including 22.1% underground and 21.1% surface water. 94% of the water withdrawn from the sea was provided for cooling purposes, corresponding to 10.2 billion m^3.

Ensuring water efficiency in agricultural, domestic and industrial water use is of great importance. In linear economy model, taking water from the primary source, using it in production, and discharging it into the receiving environment after treatment is the most common practice today. However, this is not sustainable anymore. By reclaiming wastewater through advanced purification, it is possible to create an alternative water resource, in accordance with circular economy model. In beverage industry facilities, wastewater is generated through production, cleaning, and by-products. Discharging this wastewater into the receiving environment not only creates a serious organic burden for the environment, but also exerts pressure on water resources by increasing water consumption.

Almost two-thirds of industrial water is used in food industry, and the beverage industry consumes high volumes of water [3]. During the production phase, approximately 3000 - 4500 g of conditioned water is required to produce 1000 g of beverage. The water footprint of a sugar-containing carbonated beverage in a PET-bottle has a water footprint of 150 to 300 liters of water per 0.5 liters of bottle [4]. High amounts of water use also results in high wastewater outputs. It may be possible to reduce this consumption with water recycling practices in the industry. The beverage industry requires good management of water consumption and discharge. By protecting water resources and reducing the load of organic waste discharged into the environment, deterioration of the biological and chemical structure of the receiving environments is prevented.

The amount of process water used in industrial facilities is constantly increasing. But not all the water used is for the final product. It is wasted for cooling, heating, cleaning, etc. Especially in the beverage industry, large volumes of wastewater are discharged into the receiving environment. The most suitable point for water reuse is cooling towers and boiler systems since the highest water consumption outside the product is in these operations. There are different cooling tower water quality requirements in literature covering cooling tower manufacturers, laboratories and national regulations (Table 1). To this end, the aim of this study is to produce cooling water from soft drink wastewater via membrane processes to meet the reuse requirements.

MATERIALS and METHODS

The wastewater samples were collected from the facility producing soft drinks in Elazığ city of Türkiye in 30 kg light-proof drums and kept in a cold room. The wastewater characteristics are given in Table 2. Wastewater from the facility generally originates from bottle washing and production. The flowrate of wastewater is about 400 m^3/day. UF and NF processes were applied to provide treatment to meet the cooling water quality. UF 10 kDa (commercial name GR90PP-Alfa Laval), UF 5kDa (commercial name ETNA- Alfa Laval) PES membranes and NF membranes were used in LabStak M20 membrane module in total recycle mode of filtration. Membranes were wetted in pure water for 24 h before the experiments. Rejection performance and fluxes were monitored during the experiment conducted at a trans membrane pressure (TMP) of 2 bars for UF and 4 bars for NF. Clean water fluxes were measured before and after wastewater filtration. Chemical cleaning was performed with NaOH.

Before starting the analyses, pre-treatment was performed using a coarse filter; particles in the wastewater samples were removed. Then, total hardness was measured by titrimetric methods (Standart methods: 2340) [5], using Merck brand titration kit. Turbidity (Standart Methods: 2130) and total suspended solids (Photometric Method: 8006; adapted from [6]) were measured with Hach DR-890 model spectrophotometer. COD was measured with the same spectrophometer according to the Standard methods: 5220D; pH and conductivity were measured with electronic probes (Standart Methods: 2510B) [5].

Semi-permeable commercial UF and NF membranes (Alfa Laval) were used with molecular weight cut off (MWCO) of 10 kDa and 5 kDa for UF. The UF 10 kDa membrane (commercial name AlfaLaval ETNA10 PP) is made of composite fluoro polymer material, and UF 5 kDa membrane (commercial name AlfaLaval GR90PP) is made of polyether sulfone material. NF membrane is a thin film composite.

Wastewater was forced to pass through these filters with the help of a high-pressure pump, and the membrane retained an expected portion of the substances in the wastewater. The properties of the permeate water passing to the other side were analyzed and determined. The resulting water quality values were evaluated with relevant parameters and compared by checking their compliance with the literature and manufacturer's guideline values.

Table 1. Limit values for cooling tower waters

Parameter	Unit	Value	Reference
Chemical oxygen demand (COD)	mg/L	75	[7]
Total suspended solids (TSS)	mg/L	25 100	[8] [7]
Copper	mg/L	0.5 0.1	[9] [10]
pH		7.0 – 9.0 6.8 – 7.9 6.0 – 9.0 7.8 – 8.4 7.1	[8] [11] [9] [10] [12]
Conductivity	µS/cm	2000 2300	[8] [11]
Chloride	mg/L	200 528 500 471	[8] [11] [9] [12]
Chlorine	mg/L	1	[8]
Total hardness	mg/L	50 - 600 147 900 256 6250	[8] [11] [10] [12] [7]
Alkalinity	mg/L	500 200 - 250	[8] [10]
Silica	mg/L	150 150 29	[8] [10] [12]
Sulphate	mg/L	300 1980	[11] [12]
Sodium	mg/L	310	[11]
Total organic carbon (TOC)	mg/L	5 11	[11] [12]
Phosphate	mg/L	8 2	[11] [12]

Table 2. Wastewater characteristics

Parameter	Value	
	Feed for UF	Feed for NF
COD (mg/L)	1110	254
pH	5.8	8.6
Conductivity (µS/cm)	770	540
Total suspended solids (mg/L)	152	32
Turbidity (FAU)	207	78
Total hardness (mg/L $CaCO_3$)	110	750

In the study, pressurized membrane mechanism and membrane plates were used (Figure 1). For this purpose, a pre-prepared combination of Alfa Laval brand LabStak M20 model pressurized water filtration mechanism and membrane holder were prepared. The membrane to be tested was placed in the feed system and ultrapure water was passed under 2 bar pressure for the UF membrane and 4 bar pressure for the NF membrane. In the study, the temperature was kept under control and the study was carried out at 20ºC. Every thirty minutes, the flux was measured and recorded by holding a stopwatch to calculate how many seconds it took to fill the 50 mL volumetric cylinder. Then, the wastewater was passed, and the fluxes were measured in the same period; at the same time, 50 mL samples were taken from the permeate water and feed water. These procedures are set as 2 hours each. After the wastewater passage, ultrapure water flow is started for 2 hours, and flux measurements are recorded at 30-minute intervals using the same method. Then, the membranes were removed from the system and mechanically cleaned and reinserted into the system. Pure water flow tests were conducted again to see the benefit of mechanical cleaning. After mechanical cleaning, pH was adjusted to 10.50 by adding 1% caustic solution into pure water and chemical cleaning was carried out by passing this water. After chemical cleaning, pure water was passed again, and the fluxes were recorded.

Figure 1. Membrane filtration system

RESULTS and DISCUSSION

As seen from Table 3, TSS and turbidity were completely removed, however COD and conductivity rejections were 29-65% and 0-2%, respectively. In addition, hardness was not rejected, as may be expected. It was revealed that none of the processes could meet the COD criteria of 75 mg/L for cooling towers. In addition, NF could not meet the total hardness criteria of 130 mg/L (CaCO3). However, it should be noted that the raw wastewater taken from the plant was not identical for UF and NF experiments, and the composition was much more polluted for COD in the case of UF tests and total hardness in the case of NF tests. So, there is a need to conduct further tests with another wastewater sample that would be identical for all cases.

In a different study, electrocoagulation, chemical coagulation and adsorption were applied for COD removal from beverage industry wastewater [13]. It was determined that COD removal rates were 42% with the electro-coagulation technique, while 23% removal was achieved when the chemical coagulation technique was used. On the contrary, the COD removal performance was much higher in this study; with a rate of 64-65% in the UF.

The permeate water quality obtained by the membranes was compared with the relevant criteria, where the quality criteria published by the Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7] and the cooling tower manufacturer (Baltimore Air Coil Company [8]) are quite different (Table 3). The COD limit value of 75 mg/L reported in the Communiqué could not be met. Additionally, the pH value of 5.8 seen in the UF permeate was below the range specified by the tower manufacturer.

No limit value is given for conductivity in the Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7], but the conductivity of wastewater was below the value determined by the tower manufacturer (2000 uS/cm). TSS limit value, which is 100 mg/L in the Communiqué and 25 mg/L in the tower manufacturer, was met by all three membranes tested. No criterion for turbidity is reported, and it was measured as zero in the recovered water. For total hardness, a limit value of 6250 mg/L was specified in the Communiqué and 50-600 mg/L was specified by the tower manufacturer. Since quite different contents were observed in the wastewater samples, while the limit values were achieved with UF membranes, the NF effluent hardness value remained above the tower manufacturer's criterion.

Flux decline was in the range of 10- 20% (Table 4). As the flux decline was low, cleaning had little impact on flux recovery. The mechanical cleaning and chemical cleaning with NaOH provided flux recovery of 92-95% for UF and 134% for NF.

In literature no study on the recovery of soft drink wastewater via membrane processes as a cooling water make up was available. One relevant study investigated the water conservation and reuse opportunities in a soft drink/beverage manufacturing company [14]. The authors carried out water use analysis and benchmarking in order to figure out the areas and processes with significant water saving potential. The evaluations revealed a reduction of the total specific cooling water demand of the company from 14.4 to 1.2 m^3/m^3 product, corresponding to 91.8%.

In another study performed at an oil and gas facility [11], the applicability of municipal reclaimed water as an alternative to groundwater for an industrial cooling system was investigated and the treated wastewater effluent was utilized as make up water for a 4.2 MW cooling tower. The use of reclaimed water was found to be economically viable with 27% reduction in water consumption. It is also reported that reclaimed water is becoming standard for new power plant construction as well as a viable alternative makeup water source for existing facilities that plan to expand production [12]. Regarding the high water consumption of beverage industry, more case studies are needed to widely implement water reuse applications and reduce the water footprint of soft drinks and beverages.

Table 3. Comparison of criteria for cooling towers with the rejection performance of UF and NF membranes

	Parameter					
	COD (mg/L)	pH	Conductivity (µS/cm)	TSS (mg/L)	Turbidity (FAU)	Total hardness (mg/L $CaCO_3$)
Criteria for cooling towers						
National Regulation[a]	75	-	-	100	-	6250
Cooling Tower Producer[b]	-	7 - 9	2000	25	-	50 - 600
Membrane Performance						
Feed						
UF (10 kDa)	796	5.7	572	121	162	95
UF (5 kDa)	718	5.8	572	121	162	95
NF	207	8.6	520	30	80	750
Permeate						
UF (10 kDa)	286	5.7	560	0	0	95
UF (5 kDa)	255	5.6	570	0	0	95
NF	147	8.6	530	0	0	750
Rejection (%)						
UF (10 kDa)	64	-	2	100	100	0
UF (5 kDa)	65	-	0	100	100	0
NF	29	-	0	100	100	0

[a]: Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7], Table E.7.21. Water Quality Recommended for Cooling Towers bBAC (Baltimore Aircoil Company) criteria [8]

Table 4. Flux decline and recovery for membranes

Process	Flux ($L/m^2/h$)			
	Clean water (initial)	Wastewater	Clean water (after mechanical cleaning)	Clean water (after chemical cleaning)
UF (10 kDa)	52.6	47.2	48.5	50.0
UF (5 kDa)	61.0	51.0	53.8	56.1
NF	116.3	92.6	156.3	156.3
Flux Decline (%)				
UF (10 kDa)		10		
UF (5 kDa)		16		
NF		20		
Flux Recovery (%)				
UF (10 kDa)			92	95
UF (5 kDa)			88	92
NF			134	134

CONCLUSION

Although total suspended solids and turbidity were completely removed with UF and NF, the removal of COD and dissolved substances was not fully achieved. Total hardness could not be eliminated. Therefore, it will be necessary to apply additional treatment to meet the COD and total hardness limit values. It is highly probable that required quality value will be achieved by applying single stage reverse osmosis (RO) or double stage NF.

The fact that solids are completely removed, and the hardness value is at a medium level makes it possible to use the reclaimed water in the systems by passing it through a resin before feeding it to the cooling tower. However, since the COD value has not been reduced to the 75 mg/L limit value, it is not recommended to feed the reclaimed water to the cooling tower directly. The organic pollution in the feed water can cause growth of microbiological organisms in the cooling tower. Additional biocide use may be required. However, feedwater organic load always poses a risk.

The fact that the treatment plant is at the project stage for this sample facility is promising in terms of the applicability of the results of the study. It allows the water resulting from pre-treatment to be passed through the membrane and fed into cooling systems quickly and effectively, or even fed into closed circuits and steam boilers.

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